

EXTENDED REPORT

The effect of contact lens induced oedema on the accuracy of Goldmann tonometry in a mature population

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Aim: To determine the effect of contact lens induced oedema on the accuracy of Goldmann tonometry measurements of intraocular pressure (IOP) in mature subjects.

Methods: 22 healthy subjects aged between 50 and 60 years were recruited. Corneal curvature, IOP, and central corneal thickness (CCT) were measured before and after two hours of monocular closed eye wear of a thick hydroxyethyl methacrylate (HEMA) contact lens. Measurements were then repeated at 20 minute intervals for one hour after lens removal.

Results: Both CCT (+54.1 μm) and IOP (+2.7 mm Hg) increased significantly after lens wear ($p < 0.001$, paired t test with Bonferroni correction). For the hour following lens removal, the measured IOP was correlated to the increase in CCT ($r = 0.84$, $p < 0.001$), at a rate of 1.0 mm Hg/10 μm (95% confidence interval, 0.8 to 1.2 mm Hg/10 μm , linear mixed model analysis).

Conclusions: A relatively small increase in CCT from contact lens induced corneal oedema caused an overestimation error in Goldmann tonometry measurements of IOP in healthy mature subjects.

Goldmann tonometry is the gold standard device for the measurement of intraocular pressure (IOP),¹ but studies have shown that variations in corneal properties—such as central corneal thickness (CCT),^{2–4} curvature,⁵ hydration,⁶ and rigidity⁷—may cause clinically significant inaccuracies in the measurement of IOP that can cloud the diagnosis of young adults.⁸ Recently, we reported that corneal oedema of less than 8% can cause an overestimation error in IOP measurement in young adults.⁹ This is important because the natural diurnal variation of CCT is within this range.^{10–12} As age appears to cause a decrease in hydration control,¹³ to increase the risk of glaucoma,^{14–16} and to alter corneal rigidity,^{17–23} we investigated the effect of corneal swelling on the accuracy of Goldmann tonometry in mature adults.

METHODS

Subjects

Twenty two subjects aged 50 to 60 years with good general and ocular health were recruited consecutively from the University of New South Wales (UNSW) Optometry Clinic. Study exclusions were a history of full time contact lens wear, significant ocular or systemic pathology, use of ocular drugs, and corneal astigmatism greater than 2.0 D.

Institutional review board approval was obtained from the human research ethics committee at UNSW and conducted according to the guidelines in the Declaration of Helsinki. All subjects provided written informed consent.

Procedures

Each subject underwent a screening examination which included visual acuity measurements, slit lamp biomicroscopy, and direct ophthalmoscopy to ensure that they met the inclusion criteria for the study. Central corneal curvature (EyeChek, Reichert Ophthalmic Instruments, New York, USA), IOP (slit lamp mounted Goldmann tonometer), and CCT (Pocket II pachymeter, Quantel Medical, Clermont-Ferrand, France) were measured in all subjects in one eye selected at random. A contact lens was inserted and the eye was taped lightly closed and patched for two hours. Following lens removal, corneal curvature, CCT, and IOP measurements were

repeated at 20 minute intervals for one hour. All measurements were made at a similar time of day and at least two hours after eye opening following sleep. A control eye was not considered necessary as our previous work indicated that CCT and measured IOP did not change significantly under these experimental conditions.⁹

Contact lenses

The contact lenses used were custom designed (Ciba Vision, Sydney, Australia) with a constant thickness of 0.3 mm, a diameter of 14.0 mm, and made from hydroxyethyl methacrylate (38% water content; $Dk/t = 2.8 \times 10^{-10} \text{ cm}^2/\text{s} \cdot \text{mm Hg}$). To achieve an acceptable fit, four base curves were provided.

Statistics

The software package used for statistical analysis was SPSS version 12.0.2 for Windows (SPSS Inc, Chicago, Illinois, USA). Baseline ocular characteristics were compared between the control eyes and the lens wearing eyes using the paired t test. The change in CCT and IOP was computed as the difference in the measurements between baseline and each time point. The changes in corneal curvature, CCT, and IOP over time were tested for significance using repeated measures analysis of variance (RMANOVA); Bonferroni correction was applied to all post hoc comparisons. The association of the change in IOP with changes in CCT was tested for significance using linear mixed model analysis which adjusts for within-subject correlation due to repeated measures. Equations and correlations based on this model are reported. Statistical significance was set at 5%.

RESULTS

The baseline demographic features of the study population are shown in table 1.

Abbreviations: CCT, central corneal thickness; HEMA, hydroxyethyl methacrylate; IOP, intraocular pressure

Table 1 Baseline demographics

n	22		
Age (years)	54.2 (2.7)		
Sex	11 M/11 F		
Variable	Control eye	Lens eye	p Value*
Corneal curvature (mm)	7.73 (0.17)	7.75 (0.18)	p=0.334
Central corneal thickness (µm)	538.4 (21.3)	539.4 (20.0)	p=0.607
Intraocular pressure (mm Hg)	15.6 (3.0)	15.5 (3.1)	p=0.589

Values are mean (SD).
*Significance of the difference between the control and lens wearing eye at baseline, two tailed paired *t* test.
F, female; M, male.

Corneal thickness

Figure 1 shows a significant change in CCT over time (RMANOVA, *p*<0.001), with an increase immediately after lens wear of (mean (SD)) 54.1 (13.6) µm (*p*<0.001, Bonferroni correction), which is equivalent to 10.0% oedema. The change in CCT was normally distributed (Shapiro-Wilk, *p*=0.288). Following lens removal, the cornea deswelled at a rate of 31.4 µm/h.

Intraocular pressure

Figure 2 showed that there was a significant change in measured IOP over time (RMANOVA, *p*<0.001), with an increase of 2.7 (1.6) mm Hg occurring immediately after lens wear (*p*<0.001). The increase in measured IOP was normally distributed (Shapiro-Wilk, *p*=0.056). Each measurement was significantly lower than the previous one (*p*<0.001) until the 40 minute and 60 minute measurements, which were not significantly different (*p*=1.000, Bonferroni correction).

Corneal curvature

There was no significant variation in central corneal curvature over time (RMANOVA, *p*=0.455).

Corneal thickness and intraocular pressure

Linear mixed model analysis showed that the increase in measured IOP and CCT were related by the following equation: ΔIOPG = 0.10(ΔCCT) – 3.17 (*r*=0.84, *p*<0.001). The 95% confidence interval of the slope was 0.08 to 0.12. The Goldmann IOP increased by 1.0 mm Hg for each 10 µm increase in CCT.

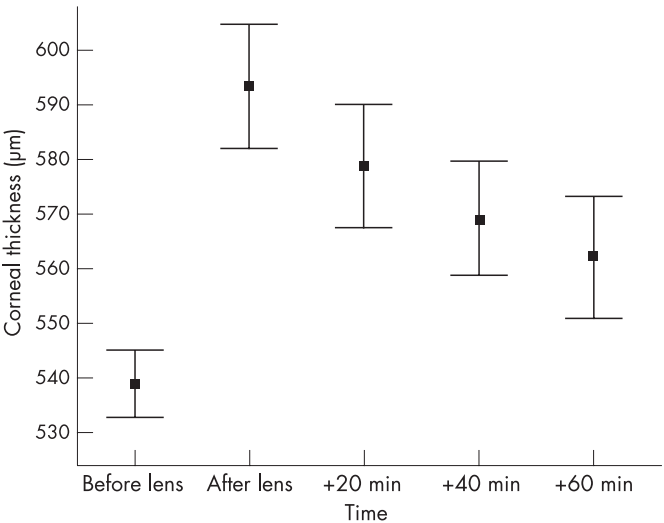


Figure 1 Mean central corneal thickness (CCT) over time with 95% confidence limits.

DISCUSSION

To the best of our knowledge, this study is the first to show that a small amount of corneal oedema induced by short term closed eye contact lens wear can cause a clinically significant overestimation of Goldmann tonometry IOP estimates in mature healthy human eyes.

Two hours of closed eye contact lens wear resulted in a CCT increase of 54.1 (13.6) µm or 10.0% (*p*<0.001, Bonferroni correction, fig 1).^{9 24 25} Following lens removal, the cornea deswelled over the next hour by 31.4 µm, which is within the range reported elsewhere.^{26 27} A significant increase in the measured IOP of 2.7 (1.6) mm Hg was also noted immediately after lens wear (*p*<0.001, Bonferroni correction; fig 2), which then decreased over time until 40 minutes after lens removal.

Previous studies have shown that the diurnal variation of IOP over a short period is insignificant provided that measurements are not taken within two hours of sleep,¹² and that the IOP does not increase systematically because of contact lens removal or eye patching,^{28 29} so the increase in the measured IOP reported in this study probably represents an overestimation error caused by contact lens induced oedema. The change in Goldmann IOP was related to the change in CCT (*r*=0.84, *p*<0.001; fig 3) at a rate of 1.0 mm Hg for every 10 µm (95% confidence interval (CI), 0.8 to 1.2 mm Hg/10 µm, linear mixed model analysis). The relation between CCT and measured IOP in this study was higher than the rate of 0.2 to 0.7 mm Hg/10 µm usually quoted for normally hydrated corneas,^{2 3 30 31} which suggests that corneal oedema causes an alteration in corneal rigidity in addition to the increase in CCT alone.

Even though CCT and IOP were both at their highest value immediately after lens wear (figs 1 and 2), the subsequent reduction of these two variables occurred at a different rate. This could indicate that the initial increase in CCT and measured IOP was coincidental, or it may indicate that a third variable such as corneal biomechanical behaviour had influenced the results. While corneal oedema may cause a change in CCT and biomechanical properties, it does not follow that these changes must be synchronised, nor that the relation is linear. In fact, as it has been noted that corneal striae do not appear until the CCT has increased by at least 6% for several hours,^{32 33} it may be postulated that stress redistribution within the swollen cornea is a dynamic process, resulting in differential and potentially non-linear effects on the accuracy of Goldmann tonometry over time; a complex dynamic relation may be one reason that there is a negative constant in the linear mixed model analysis equation.

Most previous studies have reported that corneal oedema resulted in an underestimation error in IOP measurement, but these observations were conducted in eyes with large amounts of corneal oedema, or in animal, enucleated, or epithelium-free eyes,^{6 34 35} and thus may not be relevant in the in vivo human eye. More recently, we reported that corneal oedema may instead result in an overestimation error of IOP measurement in young healthy adults when small amounts of corneal oedema were induced by closed eye contact lens wear.⁹ The findings of this study support the latter observation for mature adults, although the origin of this phenomenon remains unclear.

Although the study protocol and analysis methods described in this paper were slightly different, a comparison of the slopes of the line of best fit for the mature eyes (1.0 mm Hg/10 µm of CCT (95% CI, 0.8 to 1.2) with the previous work conducted in young eyes (average of 0.43 mm Hg/10 µm),⁹ suggests that corneal oedema may have a greater effect on Goldmann tonometry in mature eyes. It is possible that aging changes, such as a decrease in hydration control¹³ and variations in corneal structure and rigidity,^{17–21} make the cornea less capable

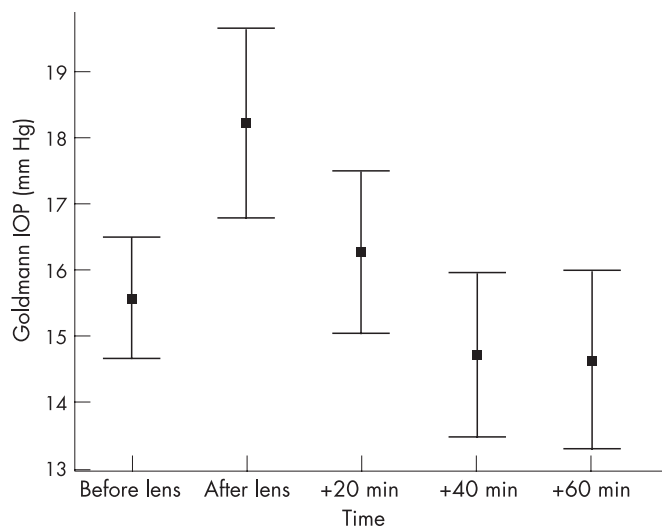


Figure 2 Mean change in intraocular pressure (IOP) over time with 95% confidence limits.

of adapting its structure to the change in fluid level, though more research will be required to provide a definitive conclusion.

All corneas show overnight swelling of around 4%¹⁰ which resolves within a one to two hour period in healthy eyes.^{36 37} However, it may be hypothesised that the decreased hydration control in older eyes may result in prolonged periods of mild corneal oedema.¹³ Thus a corneal oedema induced error in IOP of the magnitude reported in this study may become clinically significant in mature patients who are examined at early morning appointments, in eyes with mild corneal disease, or when attempting to measure the diurnal fluctuation of IOP.

The results of our study may be limited by the small sample size, the inclusion of only healthy eyes, measurement inaccuracies of the Goldmann tonometer,³⁸ and the absence of a direct measurement of IOP. Though the basic results are unlikely to change, it would be advisable to conduct future studies on a larger sample, using glaucomatous subjects and with intracameral IOP measurement. Future studies may also benefit from the consideration of a non-linear model describing corneal thickness, hydration, and the accuracy of IOP measurement.

Conclusion

Small amounts of contact lens induced oedema can cause a clinically significant overestimation of IOP by Goldmann tonometry in vivo in healthy mature adults.

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